A Comparative Study Between Sliding Mode Control(SMC) and Hybrid Control Fuzzy Sliding Mode (FSMC) for Induction Motor

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Abstract—**This paper presents a comparative study between two command strategies : control by sliding mode (CMS) and the hybrid control Fuzzy sliding mode (FSMC). The sliding mode controller is applied to an induction motor which offered us an insensitivity to parameter variations. However this control law has a disadvantage of the 'chattering' phenomenon. To remedy this problem, we combined the sliding mode control with the fuzzy logic control that the advantages of both strategies are included. The application of this controller gave as a good dynamic, insensitivity to parameter variations and an elimination of the torque chattering, demonstrated by the simulation results. The comparison of simulated results show that the hybrid control Fuzzy sliding mode (FSMC) is more robust and effective in minimizing the detuning effect in the drive due to parameter variations and model uncertainties.**

Keywords—induction motor, sliding mode control, Fuzzy Logic Control, chattering, fuzzy sliding controller.

I. INTRODUCTION

The Induction motors are widely used in many industrial applications due to their low maintenance, robustness and high performance. The vector control or field oriented control methods have been proposed so that the induction motor can be controlled like a separately excited DC motor. Indirect vector control has been applied in wide range of industrial application. In order to accomplish variable speed operation, conventional PI controllers have widely used [11]. By applying this controller induction machine achieves control performance similar to separately excited DC machine. Due to nonlinear characteristic of induction motor, linear controller such as PI controller fails to give optimum performance. This controller is also sensitive to parameter. Variation, external disturbance, loads change. To solve these problems, recently intelligent controller such as sliding mode controller (SMC), Fuzzy logic Controller (FLC) etc. have been applied to drive systems [11].

The sliding mode control is a type of variable structure system characterized by high simplicity and robustness against insensitivity to parameters variation and disturbances. This approach utilizes discontinuous control laws to drive the system state trajectory onto a sliding or switching surface in the state space. The dynamic of the system while in sliding mode is insensitive to model uncertainties and disturbances. However, the discontinuous control presents a major drawback presented in chattering phenomenon [13]. Fuzzy logic or fuzzy set theory has received attention of a number of researches in the area of power electronics and motion control. The fuzzy logic control is somewhat easy to implement because it does not need the mathematical model of a system. Hence, the interest for practical application of fuzzy logic is growing rapidly. However, it is difficult to guarantee the stability of the system because fuzzy logic controller is designed on the basis of human experience [14].

In this paper, we presented a new hybrid nonlinear control method which is based on sliding mode control and fuzzy logic method, sliding mode control approach is employed to design the induction motor speed and flux controllers. Finally, simulations and a comparison are presented to demonstrate the contribution of this approach.

II. DYNAMIC MODEL OF INDUCTION MOTOR

The dynamic modeling of Induction Motor is done in Simulink program of Matlab by utilizing its mathematical equations which are shown below [1]:

$$\begin{cases} \frac{d}{dt} i_{sd} = -\gamma i_{sd} + \omega_s i_{sq} + \frac{k}{T_r}\ \varphi_{rd} + \frac{1}{\sigma.L_s} v_{sd} \\ \frac{d}{dt} i_{sq} = -\gamma i_{sq} - \omega_s i_{sd} - p\Omega k\ \varphi_{rd} + \frac{1}{\sigma.L_s} v_{sq} \\ \frac{d}{dt} \varphi_{rd} = \frac{M}{T_r} i_{sd} - \frac{1}{T_r}\ \varphi_{rd} \\ \frac{d}{dt} \Omega = p \frac{M}{JL_r}\ \varphi_{rd}\, i_{sq} - \frac{1}{J} C_r - \frac{f}{J} \Omega \end{cases} \tag{1}$$

with:

$$k = \frac{M}{\sigma\, L_s L_r}\ ,\ \gamma = \frac{R_s + R_r \frac{M^2}{L_r^2}}{\sigma\, L_s}\ , \sigma = 1 - \frac{M^2}{L_s L_r}\ ,\ T_r = L_r/R_r$$

III. Sliding Mode Control

Sliding mode technique is a type of variable structure system (VSS) applied to the non-linear systems. The sliding mode control design is to force the system state trajectories to the sliding surface S(x) and to stay on it by means a control defined by the following equation [13]:

$$U = U_{eq} + U_c \tag{2}$$

where U_{eq} and U_c represent the equivalent control and the discontinue control respectively.

To attract the trajectory of the system towards the sliding surface in a finite time, $U_c(x)$ should be chosen such that surface in a finite time, $U_c(x)$ should be chosen such that Lyapunov function, satisfies the Lyapunov stability [13]:

$$\dot{S}(x).S(x) < 0 \tag{3}$$

The general equation to determine the sliding surface proposed is as follow [13]:

$$S(x) = \left(\frac{\partial}{\partial t} + \lambda_x\right)^{r-1} e(x) \tag{4}$$

Here, e is the tracking error vector, λ is a positive coefficient and r is the system order.

The main disadvantage in conventional SMC is chattering, which is a phenomenon of high frequency oscillation in the output, due to the high frequency switching between the functions. Chattering adversely affects the performance of the system significantly.

Thus, we search for different methods to limit this phenomenon. One approach is to replace the sign function by an intelligent control [12].

A. synthesis of the SMC controller

In the design of sliding mode control of speed and rotor flux of the system, the switching function is chosen as follows [12]:

$$\begin{cases} S_1 = K_1 e_\omega + \dot{e_\omega} \\ S_2 = K_2 e_{\varphi_r} + \dot{e_{\varphi_r}} \end{cases} \tag{5}$$

with :

$$e_\omega = \Omega^{ref} - \Omega\ , e_{\varphi_r} = {\varphi_r}^{ref} - \varphi_r \tag{6}$$

Beginning with the replacement of (6) in (5) we have:

$$S_1 = S(\Omega) = K_1\left(\Omega^{ref} - \Omega\right) + \left(\dot{\Omega}^{ref} - \dot{\Omega}\right) \tag{7}$$

$$S_2 = S(\varphi_r) = K_2({\varphi_r}^{ref} - \varphi_r) + ({\dot{\varphi}_r}^{ref} - \dot{\varphi}_r\ ) \tag{8}$$

where $K_1$and K_2 are positive gains.

The development of calculated derivatives of the surfaces gives:

$$\dot{S}_1 = \ (\ddot{\Omega}^{ref} + K_1\, \dot{\Omega}^{ref} + \frac{C_r}{J}) + \left(-K_1 + \frac{f\Omega}{J}\right) h_1 - \mu\left(i_{sq} h_2 + \varphi_r h_4\right) - \frac{1}{\sigma L_s}\mu\varphi_r u_{sd} \tag{10}$$

$$\dot{S}_2 \ = \left(\ {\ddot{\varphi}_r}^{ref} + K_2\, {\dot{\varphi}_r}^{ref}\right) + (-K_2 + \frac{1}{T_r})h_2 - \frac{M}{T_r})h_3 - \frac{M}{T_r \sigma L_s} u_{sq} \tag{11}$$

with:

$$h_1 = \mu\, \varphi_{rd}\, i_{sq} + \omega_s i_{sq} - \frac{1}{J} C_r - \frac{f}{J}\Omega$$

$$h_2 = \frac{M}{T_r} i_{sd} - \frac{1}{T_r}\ \varphi_{rd}$$

$$h_3 = -\gamma i_{sd} + \omega_s i_{sq} + \frac{k}{T_r}\ \ \varphi_{rd}$$

$$h_4 = -\gamma i_{sq} - \omega_s i_{sd} + p\Omega k\ \ \varphi_{rd}\ \ and\ \ \mu = p\frac{M}{jL_r}$$

The necessary condition for the states system follows the trajectory defined by the sliding surfaces $S_i = 0$, the equivalent part U_{eq} is the control to providing $\dot{S_\iota}$ =0 for the give:

$$\begin{bmatrix} \dot{S}_1 \\ \dot{S}_2 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix} - \frac{1}{\sigma L_s} \begin{bmatrix} \mu\varphi_r & 0 \\ 0 & \frac{M}{T_r} \end{bmatrix} \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} \tag{12}$$

with:

$$\begin{cases} F_1 = \ (\ddot{\Omega}^{ref} + K_1\, \dot{\Omega}^{ref} + \dfrac{\tau_L}{J_m}) + \left(-K_1 + \dfrac{f_m \Omega}{J_m}\right) h_1 - \\ \qquad \mu\left(i_{sq} h_2 + \varphi_r h_4\right) \\ F_2 \ = \left(\ {\ddot{\varphi}_r}^{ref} + K_2\, {\dot{\varphi}_r}^{ref}\right) + (-K_2 + \dfrac{1}{T_r})h_2 - \dfrac{M}{T_r})h_3 \end{cases}$$

we have

$$\dot{S}_1 = F + D.U \tag{13}$$

with:

$$F = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix} ; D = -\frac{1}{\sigma L_s} \begin{bmatrix} \mu\varphi_r & 0 \\ 0 & \frac{M}{T_r} \end{bmatrix} \tag{14}$$

To check the stability condition of Lyapunov ($S_i\ .\dot{S_\iota}\ < 0$) we must have:

$$\begin{cases} U_{eq} = \frac{1}{\mu\varphi_r}\ F_1 + \vartheta_\Omega sign\ (S_1\ ) \\ U_c = \frac{T_r}{M} F_2 + \vartheta_{\varphi_r}.sign(S_2\ ) \end{cases} \tag{15}$$

where ϑ_Ω and ϑ_{φ_r} are positive gains.

IV. DESIGN OF FLC CONTROLLER

It is well known as one of the disadvantages of the SMC is the Chattering phenomenon. In this section, a fuzzy control FLC is introduced to replace the function $K_{1,2}sing(S_{1,2})$, as known the trajectory of state can reach and move along the surface of change, a good dynamic steady state can be achieved by the combination of SMC and FLC [11, 14].

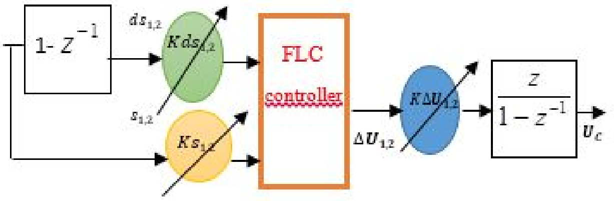

Fig.1. Block diagram of Fuzzy logic controller

V. DESIGN OF FUWWY SLIDING MODE CONTROLLER

The conventional sliding mode control is based on the discontinuous function of state variables in the system that is used to create a "sliding surface". When this surface is reached, the discontinuous function keeps the trajectory on the surface of such so that the desired system dynamics is obtained [12].

In this paper, the controllers of speed and rotor flux are substituted by a fuzzy sliding mode control to obtain a robust performance. By keeping one part of the equivalent control (SMC) and adding the fuzzy logic control (FLC) we obtain the new method control (FSMC) as shown in Fig. 4 [12].

$$U_{FSMC} = U_{eq} + U_c \tag{16}$$

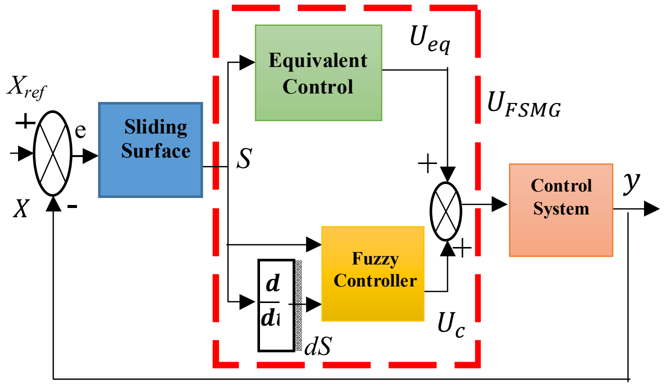

Fig.2.The structure diagram of the hybrid control FSMC

VI. SIMULATION RESULTS AND DISCUSSION

The fuzzy sliding mode controller (FSMC) for the speed control of induction motor is implemented in MATLAB/ Simulink and the results are compared with that of sliding mode controller (SMC) for showing the performance of the new method using the principle of a hybrid control by fuzzy sliding mode shown figure 3. The parameters of the simulation are given in table 2. The motor speed is set as 150 rad/s and the load of 10 N.m is applied at 0.8 s then it was removed at 1.6 s. In order to verify the robustness of proposed fuzzy sliding mode controller and sliding controller, the simulation work has been done by varying the change of rotor resistance R_r is made to reduce -15% or increase 20% from the normal value) and inertia value(the inertia value J is made to reduce -15% or increase $20\%$from the normal value).

Fig. 4 and Fig.5 shows the disturbance rejection of FSMC controller and SMC controller respectively when the machine is operated at $150\,rad/s$ under a load .Disturbance torque $10\,N.m$ is suddenly applied at $0.8\,s$, then it was eliminnated at $1.6\,s$. The performance comparison is given in table1. It is observed that the rise time with SMC controller is 0.1469 sec which is reduced to 0.12 sec with FSMC. The peak overshoot and steady state error are completely eliminated with FSMC which are 0% and 0.04% respectively with SMC controller. But the setting time of $0.1396\,sec$ with FSMC is reduced to $0.0835\,sec$ with SMC .From the results it is clear that a fuzzy sliding mode controller can perform better than that of sliding mode controller in terms of rise time, overshoot ad steady state error, maintain the decoupling between a torque-flux and reduce the chattering phenomenon.

In order to verify the robustness of proposed both FSMC and SMC controllers, we opted for variations of -15% to 20% of the nominal value R_r and J during the simulation. From the results presented in Fig.6 and Fig.7 There is no effect on the performance of the fuzzy sliding mode control strategy which is insensitive to variations of rotor resistance R_r and the moment of inertia J . For the robustness of control, a variation of the moment of inertia J, It is clear that the FMSC controller is more robust than the smc controller.

A comparison between the speed control of the IM by a SMC and a FSMC is presented in fig. 8. This comparison shows clearly that the FSMC gives good performances and torque chattering is decreased when compared with a SMC controller.

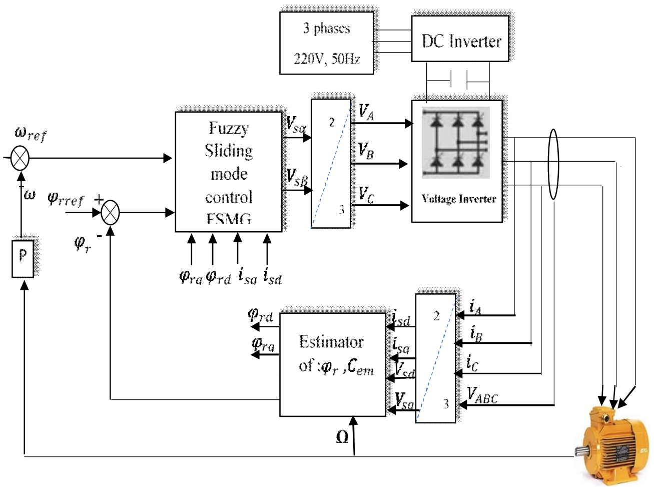

Fig.3.Block diagram of the proposed FSMC

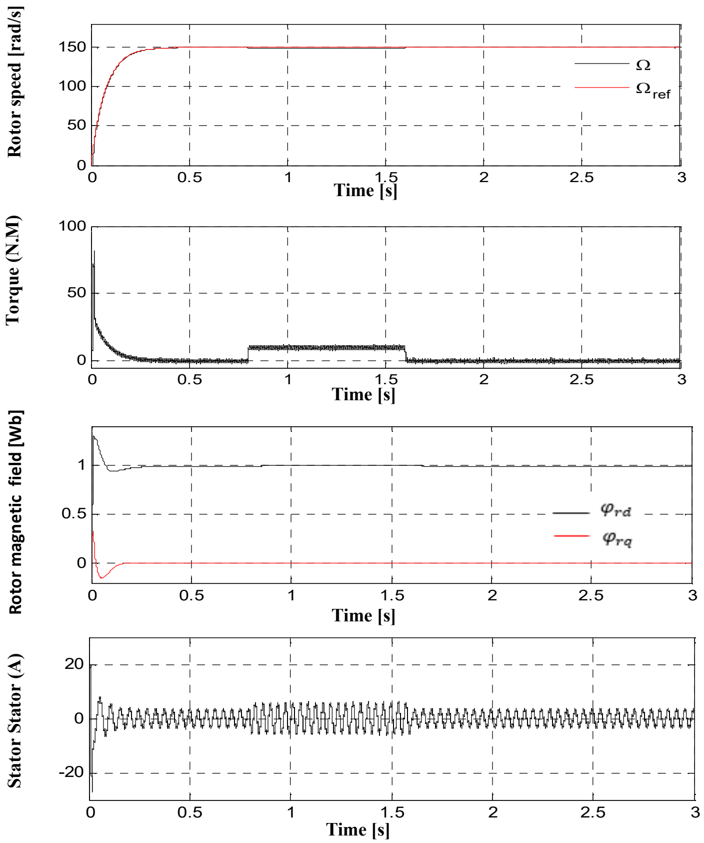

Fig. 4– Simulation results application of a load torque with FSMC

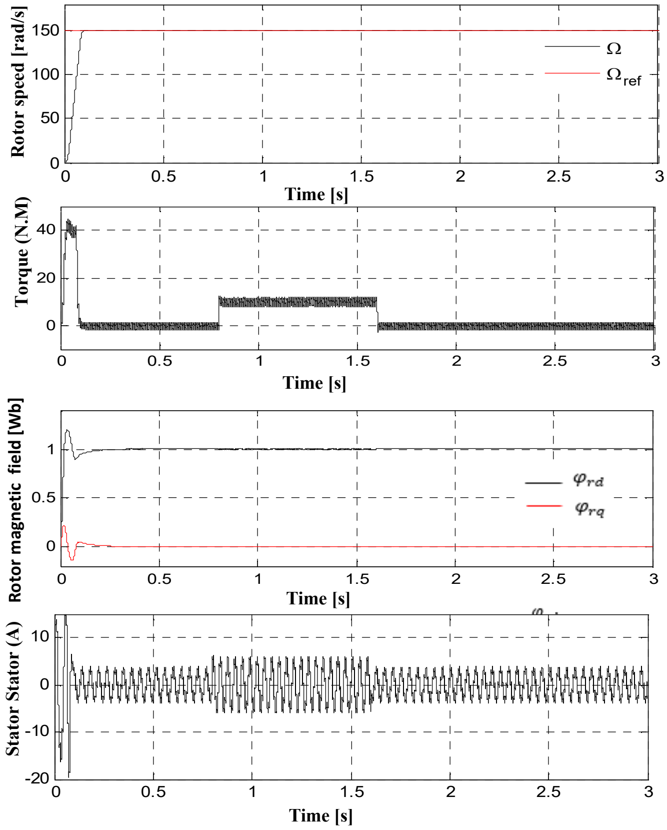

Fig. 5.Simulation results application of a load torque with SMC

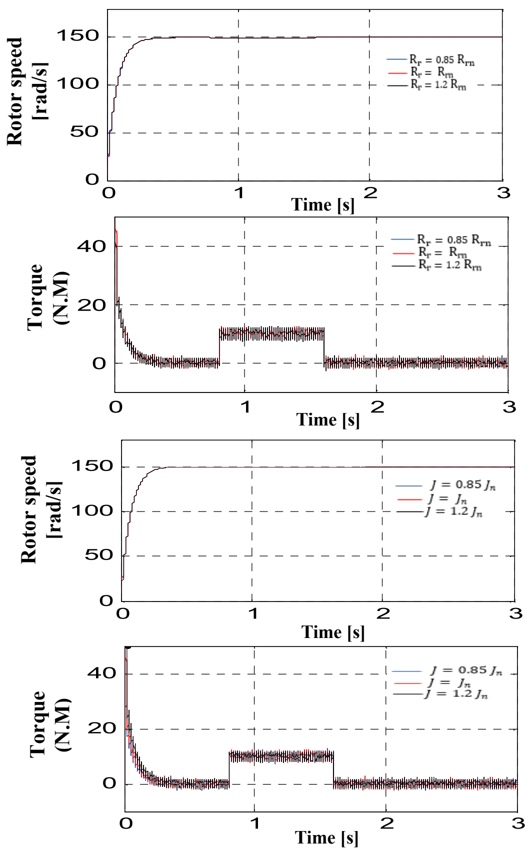

Fig. 6– Answer of FSMC with variation of(15 % and + 20%) R_r and J

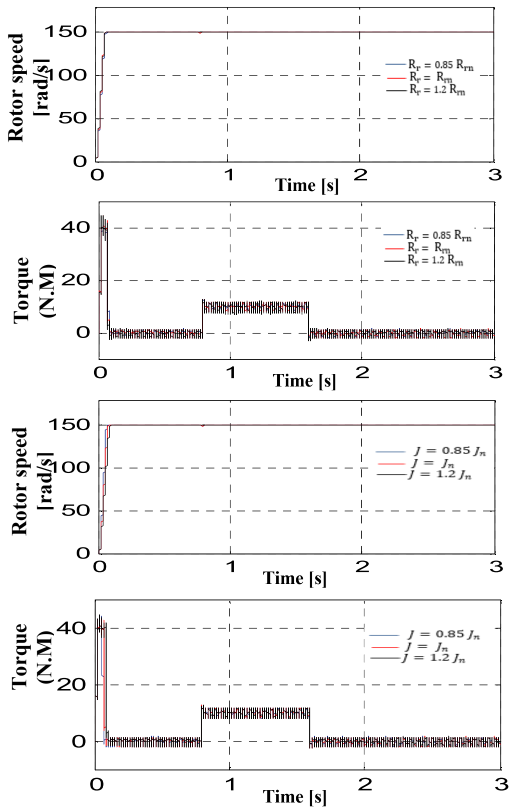

Fig. 7. Answer of SMC with variation of(15 % and + 20%) R_r and J

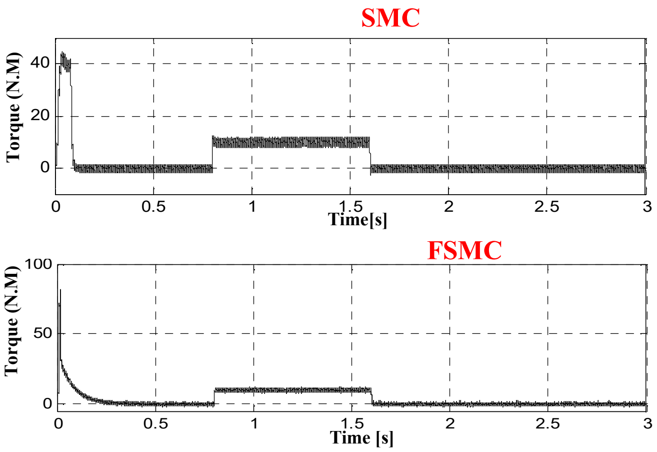

Fig. 8. Simulated results comparison between the SMC and FSMC

TABLE.1. Results of FSMC and SMC

	Rise time at 5% (s)	Setting time	Overshoot %	steady state error (rad/s)
SMC	0.1469	0.0835	0.04%	0.015
FSMC	0.12	0.1369	0%	0.01

VII. CONCLUSION

In this paper, a new type of fuzzy sliding mode controller (FSMC) is presented, the proposed control structure combines: the intelligence of fuzzy logic with the Sliding Mode technique. Simulation results indicate that the proposed approach has the advantages of simplicity and insensitivity to motor parameters and an elimination of the torque chattering.

The FSMC control gives fast dynamic response with no overshoot and zero steady-state error. The decoupling between torque flux is verified.

The comparison between the speed control of the IM by a SMC and FSMC shows clearly that the FSMC gives good performances and torque chattering is decreased when compared with a SMG controller.

APPENDIX: Motor Data

Rated power	1,5	kW
voltage (Δ/Y)	220/380	V
current (Δ/Y)	6,4/3,7	A
speed	1420	tr/mn
Load torque	10	Nm
frequency	50	Hz
R_s	4,85	Ω
R_r	3,805	Ω
L_s	0,274	H
L_r	0,274	H
L_m	0,258	H
J	0,031	Kg.m²
f	0,00114	N.m.s/rad
p	2	/

NOTATIONS

v_{sd} : Direct stator voltage
v_{sq} : Stator voltage quadrature
i_{sd} : Direct stator current
i_{sq} : Stator current quadrature
ω_s : Electrical synchronous speed
ω_r : Electrical rotor speed
ω_{ref} : Reference speed
Ω : Rotor speed
C_{em} : Electromagnetic torque
C_r : Load torque

REFERENCES

[1] M.Zerikat, R.F.Abdelgoui, Proceeding « Comparaison des Performances des régulateurs PI et PI-Flou à gains adaptés pour la commande vectorielle indirecte d'une machine asynchrone triphasée »,Third International Conference on Power Electronics and Electrical Drives ICPEED'14. Oran, December 10/11-2014

[2] Abdelgoui R.F « Conception d'un contrôleur à Logique Flou Basé sur la théorie des modes glissants appliquée à la machine asynchrone triphasée »,mémoire de Magister.ENP d'Oran 2016.

[3] Divya Rai,Swati Sharma, Vijay Bhuria «FUZZY SPEED CONTROLLER DESINGN OF THREE PHASE INDUCTION MOTOR » , International Journal of Emerging Technology and Advanced Engineering

[4] Arun Kumar R « Indirect Field Oriented Control of Induction Motor Using Fuzzy Logic »

[5] Comparative Study of Proportional–Integral,Sliding Mode, and Fuzzy Logic Controllers for Power Converters, V. S. C. Raviraj and P. C. Sen, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 33, NO. 2, MARCH/APRIL 1997

[6] Neural and Fuzzy Logic Control of Drives and Power Systems.M.N. Cirstea, A. Dinu, J.G. Khor,M. cCormick Newnes.2002.

[7] Fuzzy Control Systems Design and Analysis: A Linear Matrix Inequality Approach,Kazuo Tanaka, Hua O. Wang.2010

[8] Mohammad Abdul Mannan1, Asif Islam and all « Fuzzy-Logic Based Speed Control of Induction Motor Considering Core Loss into Account »

[9] Baghli. L, « Contribution à la Commande de la Machine Asynchrone, Utilisation de la Logique Floue, des Réseaux de Neurones et des Algorithmes Génétiques », Thèse de Doctorat, Université Henri Poincaré, France, 1999.

[10] Zerikat M., Chekroun S., "Robust tracking speed control for induction motor drive based fuzzy logic", 2006

[11] Sumit Sunil Rashinkar and Subhash S. Sankeshwari « SLIDING-MODE CONTROLLER BASED INDIRECT VECTOR CONTROL OF INDUCTION MOTOR », International Journal of Advances in Engineering & Technology, Nov., 2014

[12] Ismail Bendaas, Farid Naceri « A New Method to Minimize the Chattering Phenomenon in Sliding Mode Control Based on Intelligent Control for Induction Motor Drives », SERBIAN JOURNAL OF ELECTRICAL ENGINEERING ,Vol. 10, No. 2, June 2013, 231-246

[13] A. Bennassar, A. Abbou, M. Akherraz, and M. Barara « Sensorless sliding mode control of induction motor using fuzzy logic Luenberger observer » Recent Advances in Neural Networks and Fuzzy Systems, ISBN: 978-1-61804-227-9.

[14] D-H Kim, H-J Ryoo, Y-J Kim and G-H Rim « Speed control system of induction motor with fuzzy-sliding mode controller for traction applications », Computers in Railways III, J Allan, RJ Hill, CA Brebbia, G Sciutto and S Sone (Editors). ISBN 1-85312-913-5 .2002

[15] Arun Prasad K.M.a, Unnikrishnan A.b and Usha Nair « Fuzzy Sliding Mode Control of a Switched Reluctance Motor », Global Colloquium in Recent Advancement and Effectual Researches in Engineering, Science and Technology (RAEREST 2016).